The Cosmogony of Laplace. By Daniel Kirkwood, LL.D., Bloomington, Indiana.

(*Read before the American Philosophical Society, Sept. 19th,* 1879.)

Laplace's celebrated nebular hypothesis was first distinctly stated in his *Système du Monde.** The reasoning by which it is there sustained is general, and it does not appear that the author made any effort to test his theory by analysis. The law of the conservation of energy was then undiscovered, and hence data, which now seem available for a critical examination, were entirely wanting. Let us consider the hypothesis in some of its obvious aspects.

1. It is assumed by Laplace that nebulous rings were abandoned only in the vicinity of the present orbits of the planets. While I have for many years believed that the matter of the solar system originally existed in a gaseous condition, and hence that *a* nebular hypothesis in *some* form must furnish the true explanation of the planetary motions, I have more than once ventured the opinion that this assumption of Laplace is wholly unwarranted. I make a single quotation from the Monthly Notices of the Royal Astronomical Society for January, 1869 :

"The known facts in regard to the zone of minor planets, as well as the phenomena of Saturn's rings, seem to demand a modification of the nebular hypothesis as generally held. No reason has ever been assigned why the solar nebula should not have abandoned rings at distances intermediate between the present orbits of the planets. On the contrary, it seems highly probable that, after first reaching the point at which gravity was counterbalanced by the centrifugal force arising from the rotation of the contracting spheroid, a continuous succession of narrow rings would be thrown off in close proximity to each other, and revolving in different periods according to Kepler's third law."

The view thus expressed in 1868 has never been called in question, and I have seen no reason to modify it. The *ring* theory thus seems to require that after matter began to be thrown off at the equator of the revolving mass, the process should have been almost continuous until the nebula became transformed into a close system of rings presenting the appearance of a thin plate or disk. The theory would thus fail to account for the formation of the solar system as it actually exists.

2. But even if we adopt Laplace's theory of ring formation, we at once encounter difficulties no less serious. It is obvious, on the slightest examination, that the mutual attraction of different portions of a zone could have very little influence in bringing its molecules together around a common nucleus. Laplace, it is true, supposed the fragments of a ring to have been thus collected into a single planet. "Almost always," he says, "each ring of vapors ought to be divided into several masses, which, being moved with velocities that differ little from each other, should continue to revolve at the same distance from the sun. These masses should assume

* Published at Paris in 1813.

a spheroidal form, with a rotary motion in the direction of that of their revolution, because their inferior particles have a less real velocity than the superior; they have, therefore, constituted so many planets in a state of vapor. But if one of them was sufficiently powerful to unite successively by its attraction all the others about its centre, the ring of vapors would be changed into one sole spheroidal mass, circulating about the sun, with a motion of rotation in the same direction with that of revolution."

In regard to the mutual attraction here referred to, it may be remarked, that two parts of the Neptunian ring on opposite sides of the sun could produce no sensible perturbation of each other's motion. If, moreover, the fragments of any ring were distributed around the orbit with approximate uniformity, their mutually disturbing effects would nearly destroy each other. That this state of things should have obtained in the case of some of the eight principal planets is extremely probable. The theory, therefore, of planetary aggregation by the attraction between different parts of the rings, requires an indefinite antiquity of the solar system. Let us suppose, then, that the planet-forming process was due to the different velocities of the fragments into which a ring had been broken up. Take, for example, the ring which was transformed into Neptune. Let us assume that two fragments, A and B, differed in longitude by 180°, and that the mean distance of the centre of gravity of A from the sun's centre exceeded that of B by 1000 miles. It is then easy to show that the corresponding difference of their angular velocities would not bring them together around the same nucleus in 15 millions of years. But even after *all* the fragments had thus been collected, other millions of years—assuming with Laplace that the united mass was still in the gaseous form—would be required for the process of condensation. The supposition we have made is not an extravagant one. In Laplace's cosmogony, therefore, hundreds of millions of years are involved in the separate history of a single planet. Is so great an implied age of the solar system admissible?

According to Helmholtz, whose theory is now generally accepted, the sun's heat is but the transformed motion of its parts condensed or drawn together by the force of gravitation. Now, the law of the conservation of energy enables us to calculate the age of the sun, knowing (1) the amount of solar heat radiated in a given time, and (2) the amount produced by a given contraction of the sun's mass. It has thus been found that condensation from the distance of the nearest fixed stars to the sun's present volume, would have kept up a supply of heat equal to the present for about twenty millions of years. This estimate, it will be understood, is based on the assumption that the sun's density is uniform from centre to surface. If, as is altogether probable, the density increases towards the centre, the age of the sun may be considerably greater.*

* "On the only hypothesis science will now allow us to make respecting the source of the solar heat, the earth was, twenty millions of years ago, enveloped in the fiery amosphere of the sun."—*Prof. Simon Newcomb in the N. A. Review, for July*, 1876.

3. The difficulty here presented is one of no small importance. If removed, however, we are immediately met by another perhaps still more formidable. Assuming the increase of Neptune's radius to have been uniform during the time required for the accumulation of the ring around a single nucleus, the daily superficial deposit would be less than one-sixtieth of an inch; the density being equal to the present density of the planet. This extremely slow transformation of the nebulous zones would develop little heat; so that the planets would be nearly cold during the process of their formation. Laplace's theory, therefore, obviously fails to account for the origin of satellites.

4. It is easy to show that the period of a rotating nebula in the process of condensation would vary as the square of the radius. If the solar nebula, therefore, rotated once in 164.6 years when it filled the orbit of Neptune, its period when it had contracted to the orbit of Uranus ought to have been 67 years; at the orbit of Saturn, 16.7 years; at that of Jupiter, 4.94 years, &c., &c. This obvious inconsistency with Kepler's third law* has been noticed by astronomers, and recourse has been had to the additional supposition that the rate of variation of density from surface to centre was continually changing through all the cycles of planetary formation.† Till this latter hypothesis—invented to sustain the hypothesis of Laplace—shall itself have been placed on a basis of facts, the superstructure must be regarded as eminently unstable.

Conclusion.

It has been shown (1) that the hypothesis of Laplace gives no explanation of the immense intervals between the planetary orbits; (2) that, apart from this objection, the periods required for the formation of planets from nebulous rings are greater than the probable age of the solar system; (3) that it fails to account for the origin of satellites; and (4) that it is apparently incompatible with a known physical law. The conclusion seems inevitable that this celebrated hypothesis must yet be abandoned, or that its principal features must be essentially modified.

* Let r, r', and t, t' represent the radii and periods of rotation of the solar nebula at two different epochs; then $t : t' :: r^2 : r'^2$. But by Kepler's third law, $t : t' :: r^{\frac{3}{2}} : r'^{\frac{3}{2}}$.

† See the able and interesting memoir on the Nebular Hypothesis by Prof. David Trowbridge, in the Am. Journal of Science for Nov., 1861.